

Ten Years of the CDF Silicon Vertex Detector: Performance and Status

Miguel N. Mondragon

Fermilab

On behalf of the CDF Silicon Group

New Perspectives 2011
Fermilab

May 31, 2011

Overview

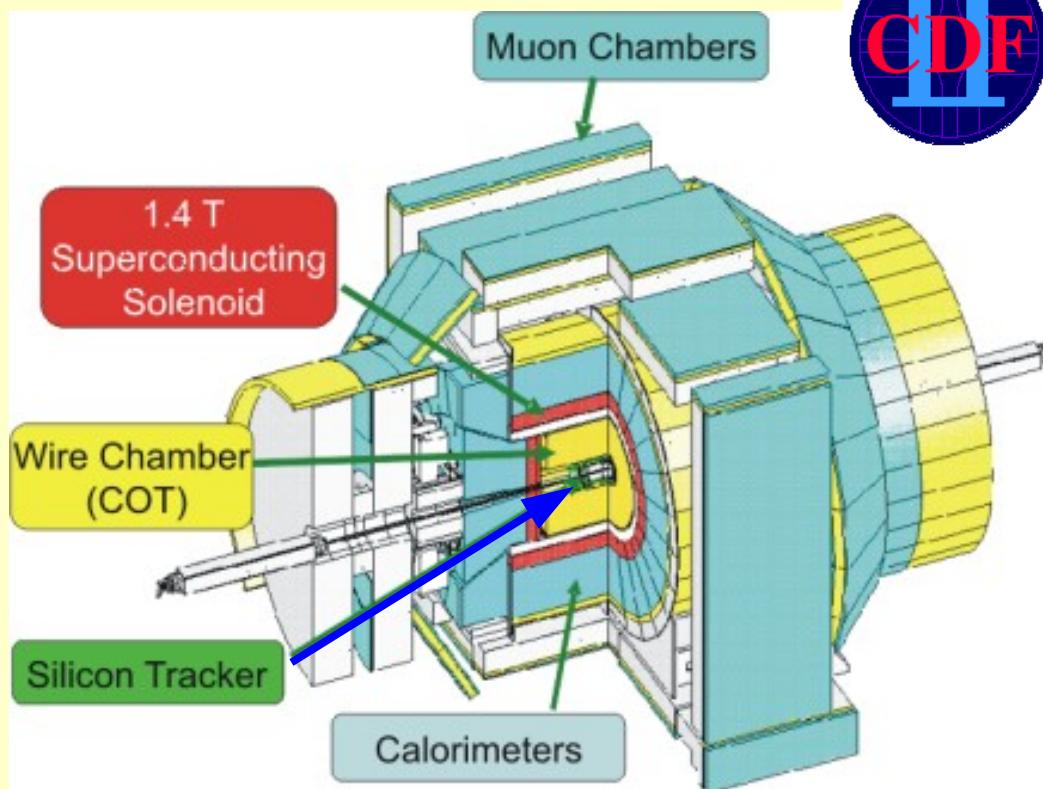
- Overview of the Silicon Detectors at CDF
- Radiation Damage
- Global Performance
- Conclusions

Tevatron

- Scheduled end of operations:
September, 2011
- Present delivered luminosity:
 $\sim 11 \text{ fb}^{-1}$
- Expected delivered luminosity at
the end of operations: $\sim 12 \text{ fb}^{-1}$

CDF

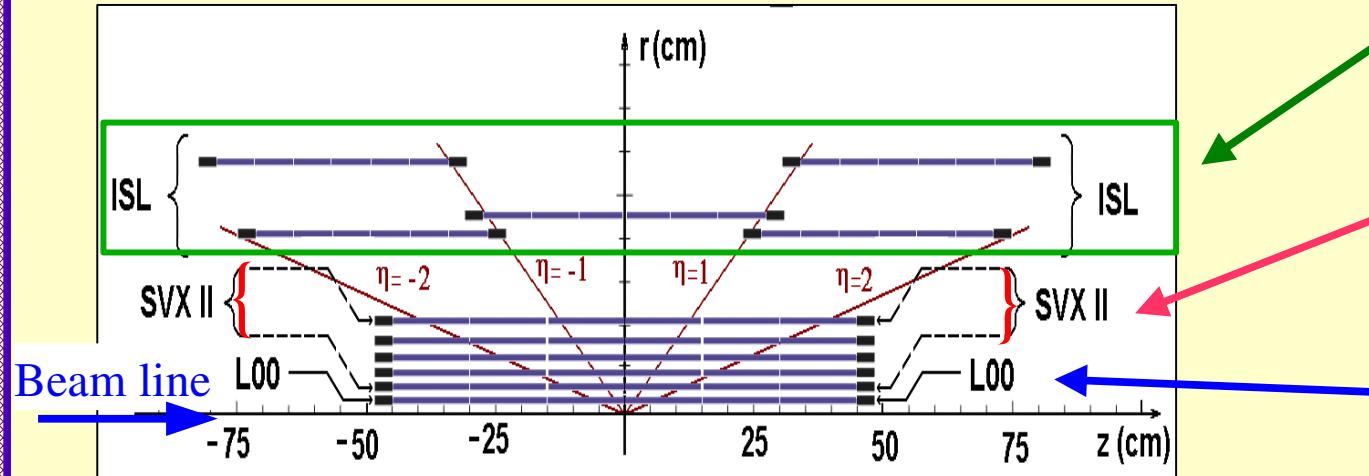
- Much of the physics program depends on Heavy-Flavor tagging (top-, b-quark physics, low-mass Higgs boson search)
- Silicon detectors essential for vertex positioning of HF decays



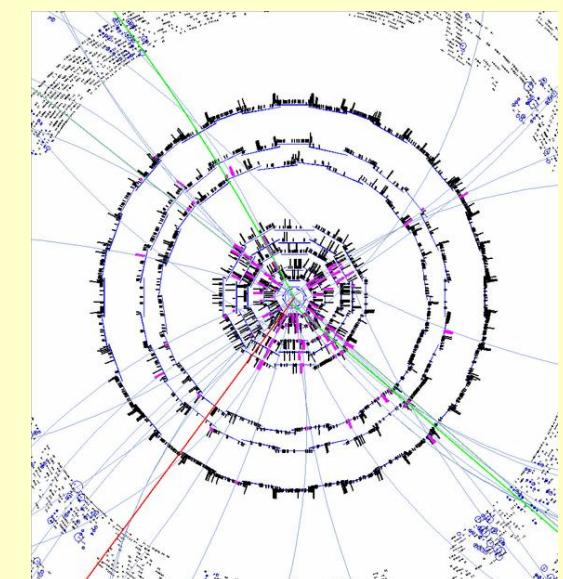
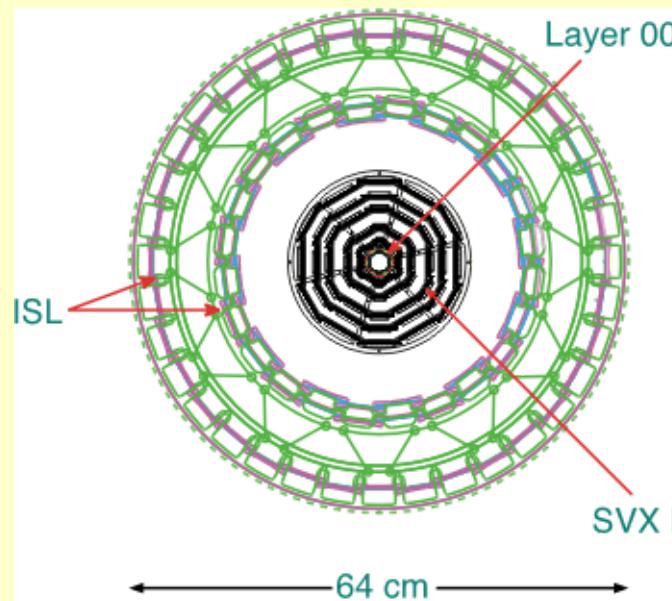
The Silicon Detector

Three microstrip subdetectors, “p” strips on “n” bulk

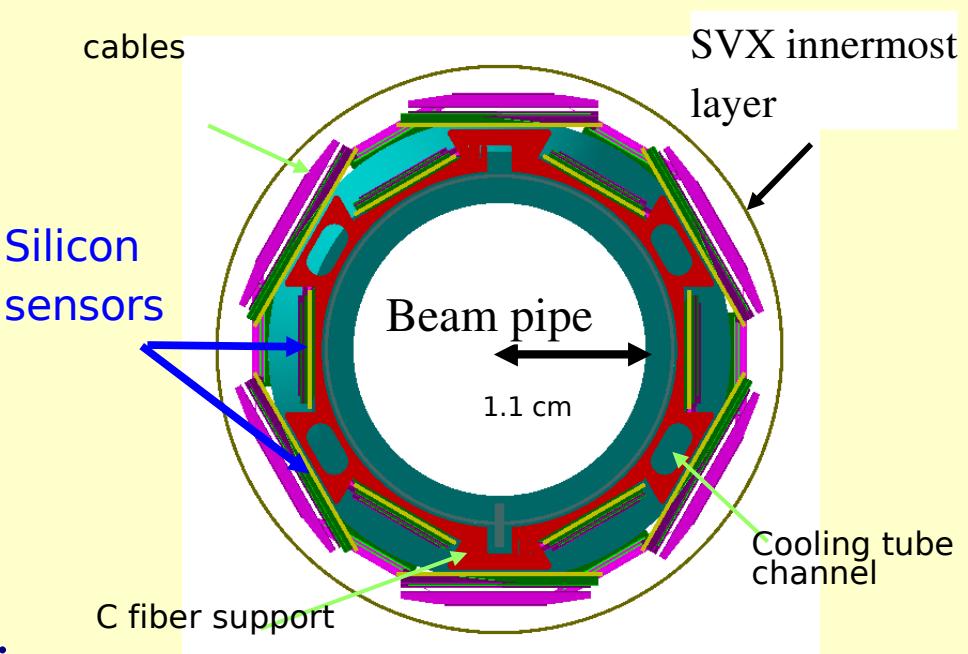
ISL: longer in z for forward coverage
SVX II: the main subdetector (~60% of the channels)
L00: mounted on the beam pipe



- 7-8 concentric layers
- 7 m^2 of silicon
- 722,432 channels

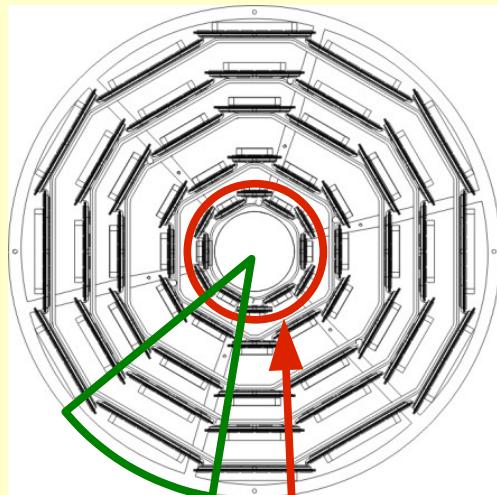


The L00 Subdetector



- Mounted directly on the beam pipe
- Designed to improve track impact parameter resolution
- Single sided sensors (axial strips). Readout strip pitch $50\mu\text{m}$
- Modules by three manufacturers:
 - ◆ Hamamatsu , 36 “wide” modules at $r=1.62\text{ cm}$
 - ◆ SGS Thomson, 10 “narrow” modules at $r=1.35\text{ cm}$
 - ◆ Micron, 2 “narrow” modules (oxygenated – more radiation tolerant)

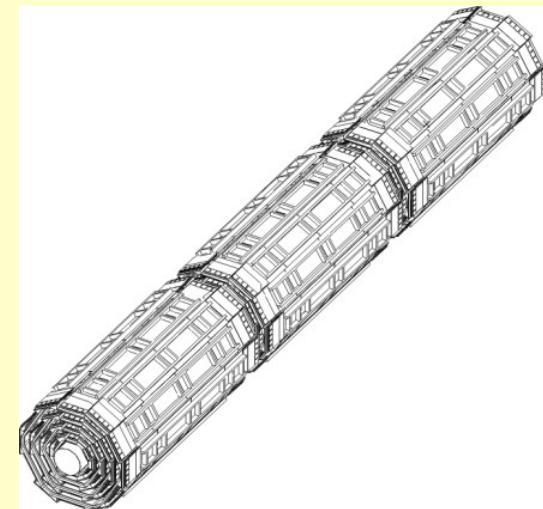
The SVX II Subdetector



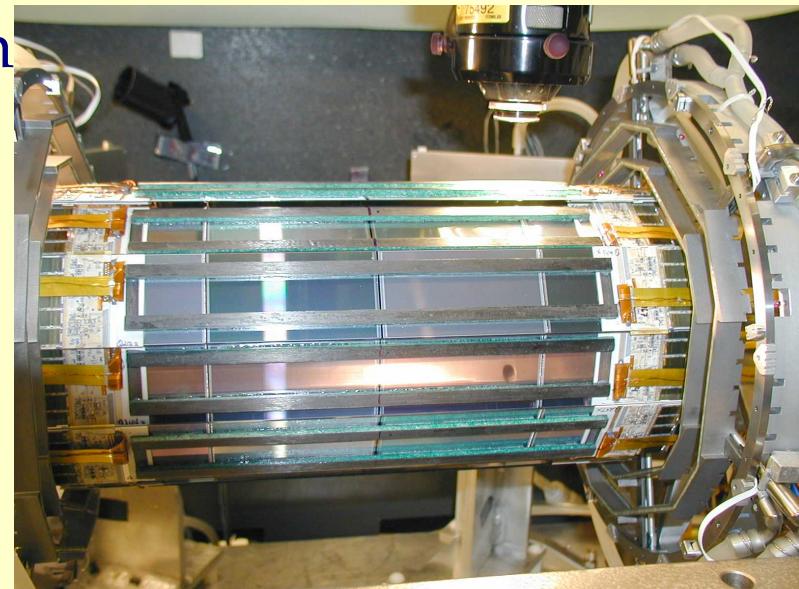
wedge

SVX-Layer 0 (72 sensors)

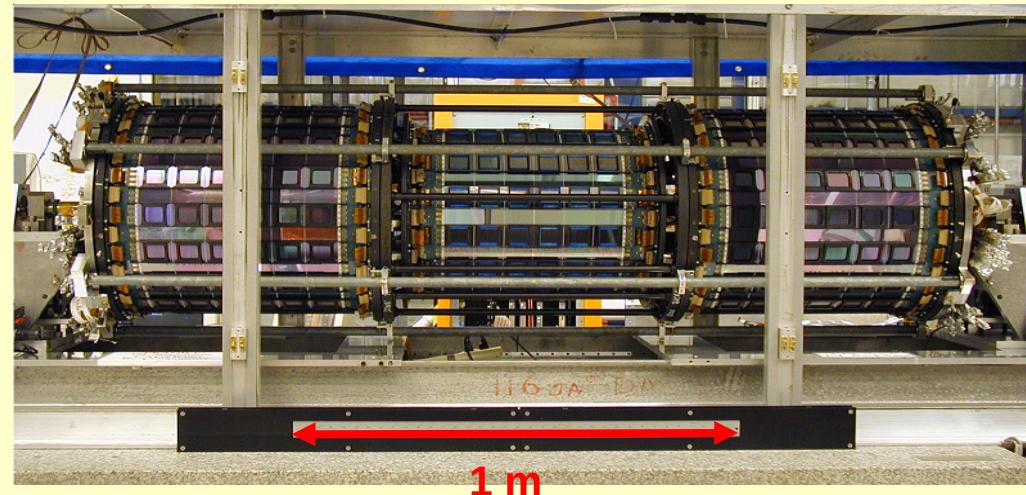
- Double sided sensors (built-in strips on both sides) for ϕ and z positioning
- Radial segmentation: 5 layers
- ϕ segmentation: 12 wedges
- Axial segmentation: 6 bulkheads
- Strip pitch 60-140 μm
- Radius: 2.5 to 10.7 cm



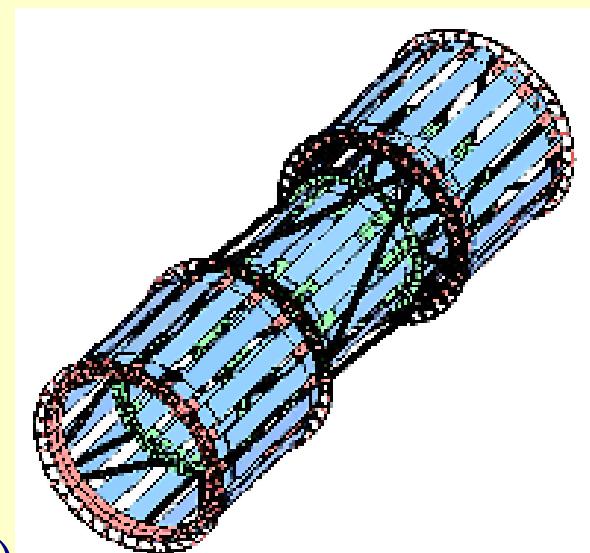
- Hamamatsu, Layers 0, 1, 3. Axial (ϕ)/ z strips
- Micron, Layers 2, 4. Axial/small-angle stereo strips



The ISL Subdetector

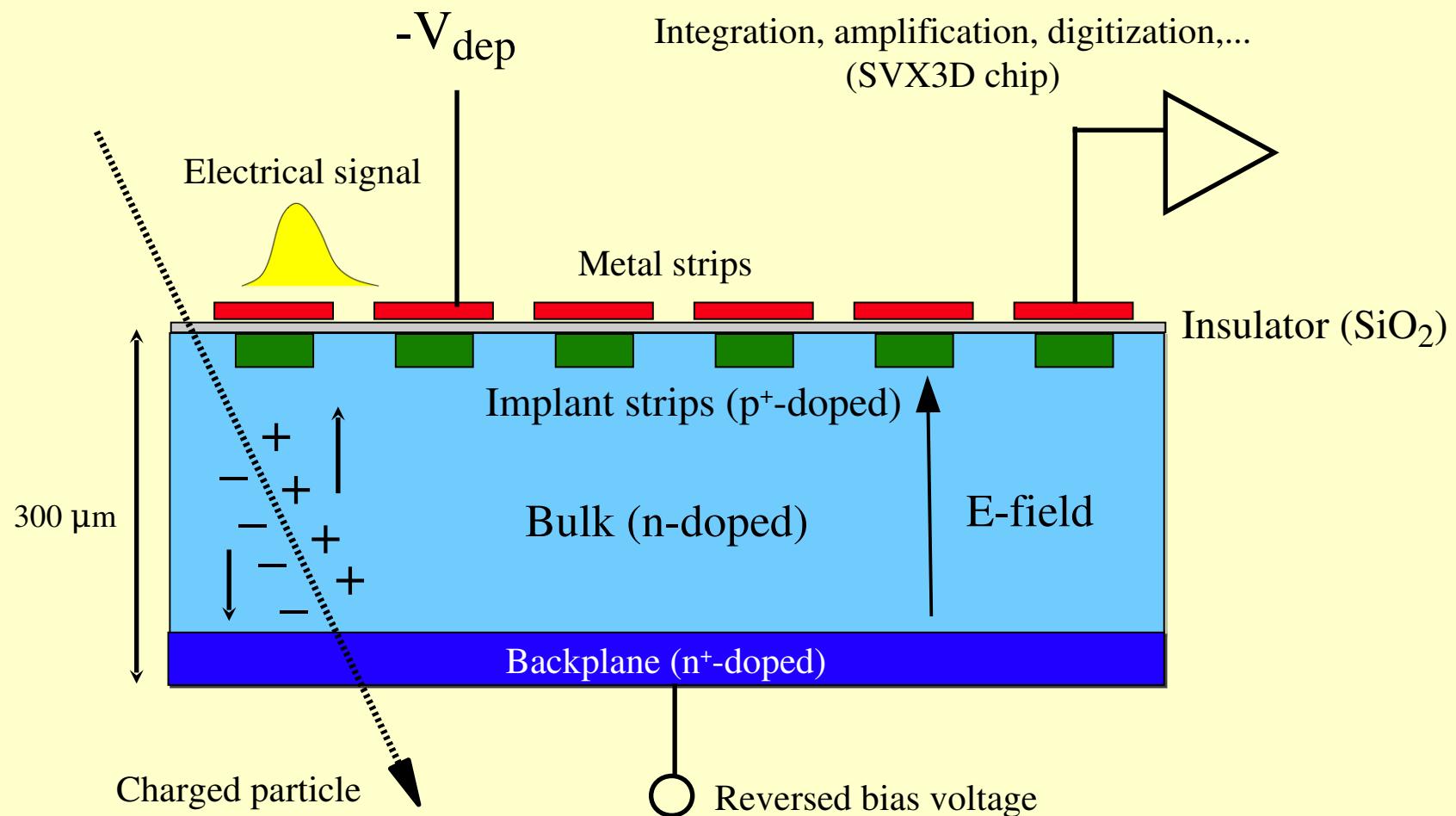


- Located between SVX II and the central drift chamber (COT)
- Designed to improve track reconstruction and linking to the central drift chamber (especially at forward coverage)
- Three layers
 - ◆ central ($|\eta| < 1$) and $r = 22$ cm
 - ◆ Forward ($1 < |\eta| < 2$) and $r = 20$ cm
 - ◆ Forward ($1 < |\eta| < 2$) and $r = 28$ cm
- Double sided sensors (axial and small-angle stereo strips)



Basic Principle of Silicon Strip Sensors

Single sided sensor



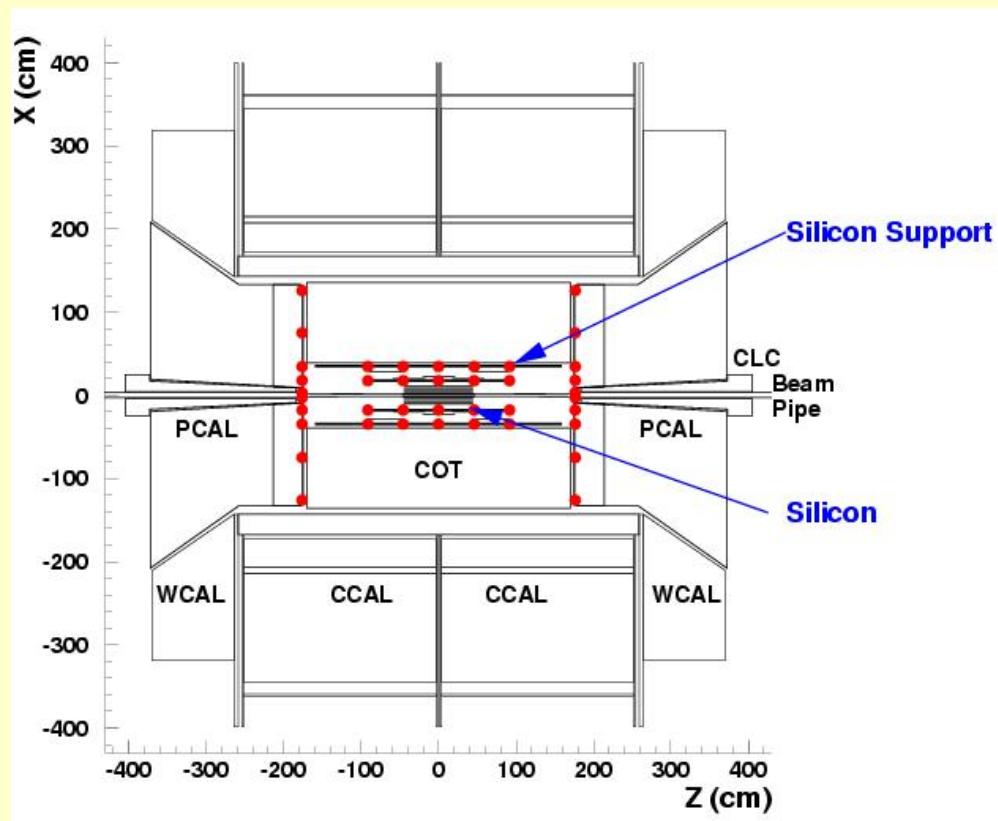
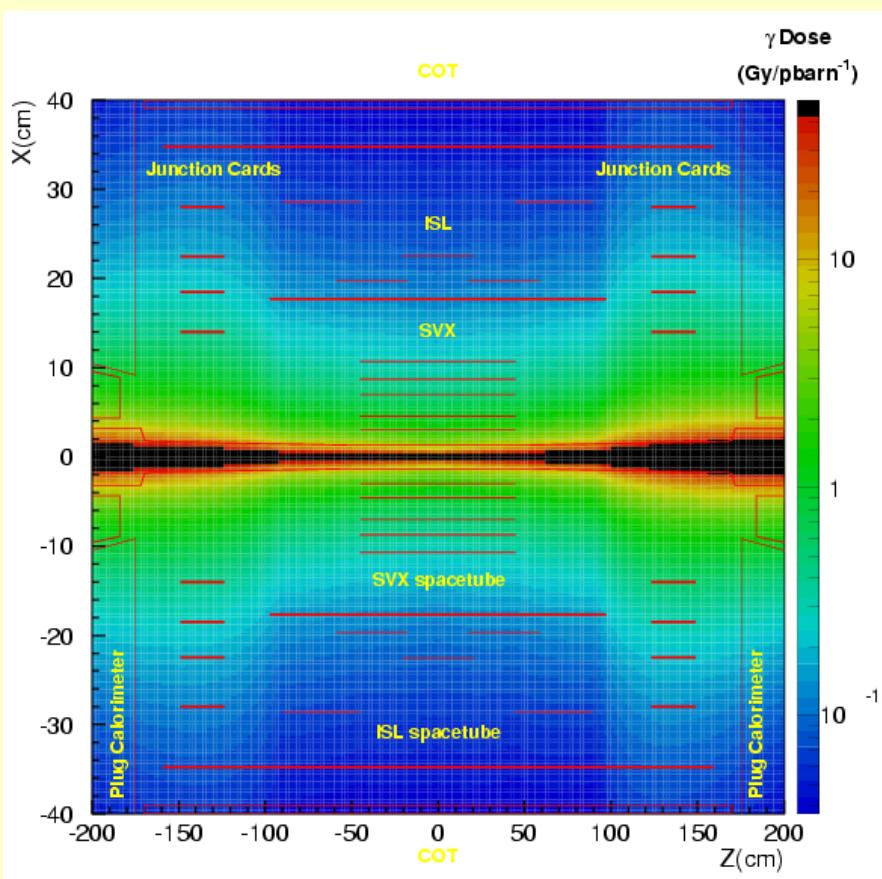
Full depletion gives the maximum collection of charges (minimizes recombination)

Radiation Damage

Tracking Volume Radiation Field

The radiation field has been measured and modeled at CDF using 916 dosimeters (TLDs),

R.J. Tesarek *et al.*, NIM A514, 188 (2003)



Locations of 916 Thermal Luminescent Dosimeters (TLDs) in the CDF tracking volume.

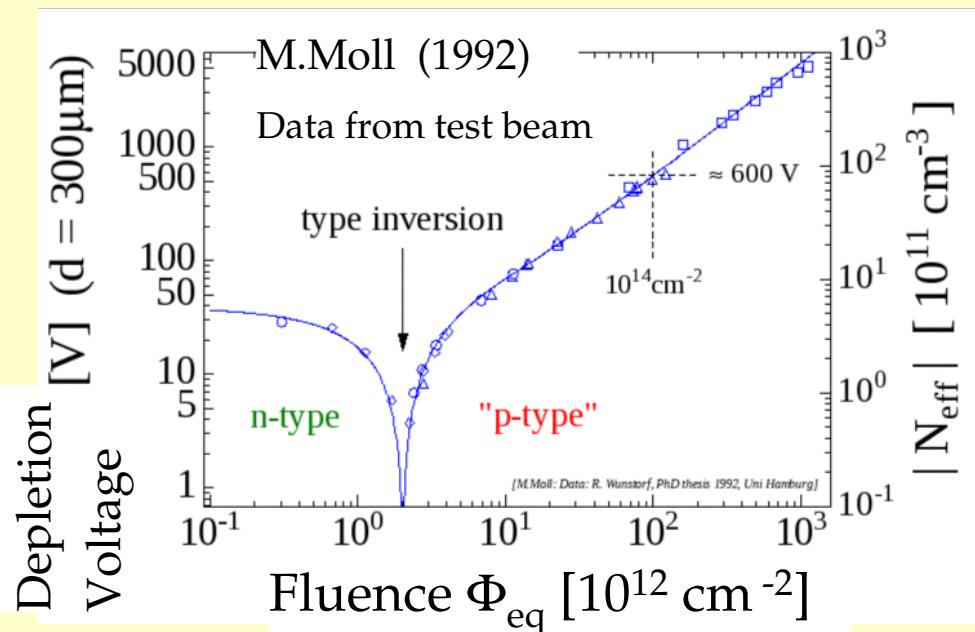
A Model of Radiation Damage

In addition to ionization, part of the radiation produces crystal defects

Some complex crystal defects with vacancies can trap electrons and change the electrical properties by removing donors and creating acceptors

Parametrization: $\Delta N_{\text{eff}}(\Phi, t, T) = \Delta N_C(\Phi) + \Delta N_Y(\Phi, t, T)$

$$\Delta N_C(\Phi) = N_{C0}(1 - e^{-c\Phi}) + g_C \Phi, \quad \Delta N_Y(\Phi, t, T) = g_Y \Phi [1 - 1/(1 + t/\tau_Y(T))]$$



- With sufficient radiation the “n” bulk turns into a “p-like” bulk
- Type inversion
- Depletion voltage follows the concentration of “dopants”

$$V_{\text{dep}} \sim |N_{\text{eff}}| d^2$$

M.Moll, *PhD Thesis*, (1992) Uni Hamburg;
papers by RD2, RD50 Collaborations,...

Radiation Damage on Operations

Observable effects of Radiation Damage

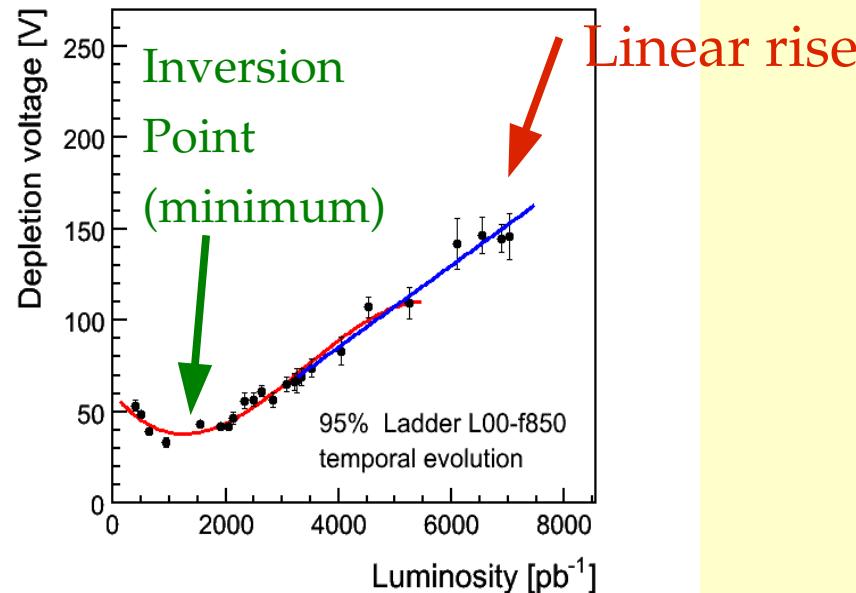
- Increased depletion voltage (above a minimum)
- Lower Signal-to-Noise ratio (smaller collected Signal, larger Noise)
- Increased reversed-bias current

Operational Implications

- Increased bias voltage required
- Limitations on voltage: power supply limit, sensor breakdown
- Signal-to-Noise ratio must be kept good enough for physics analyses

The CDF Silicon Detector was designed to withstand radiation up to $\sim 3 \text{ fb}^{-1}$ of integrated luminosity

Evolution of Depletion Voltage



As radiation damage increases:

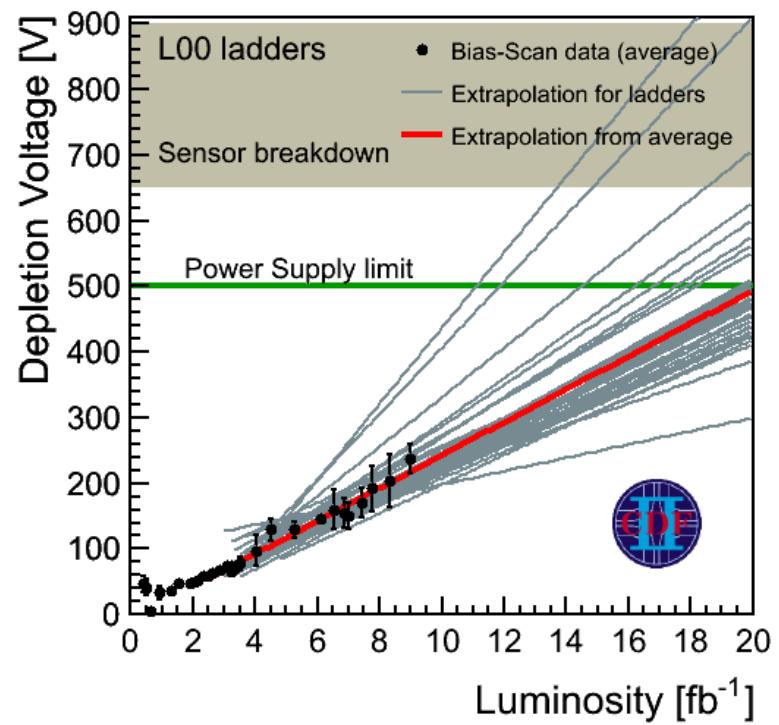
- Required depletion voltage rises
- Need to increase reversed-bias V to keep good efficiency

Measured V_{dep} at different integrated luminosities:

- Fit a 3rd degree polynomial around minimum
- Linear fit above inversion point

The linear rise can be extrapolated to make predictions...

Outlook of Depletion Voltage for L00

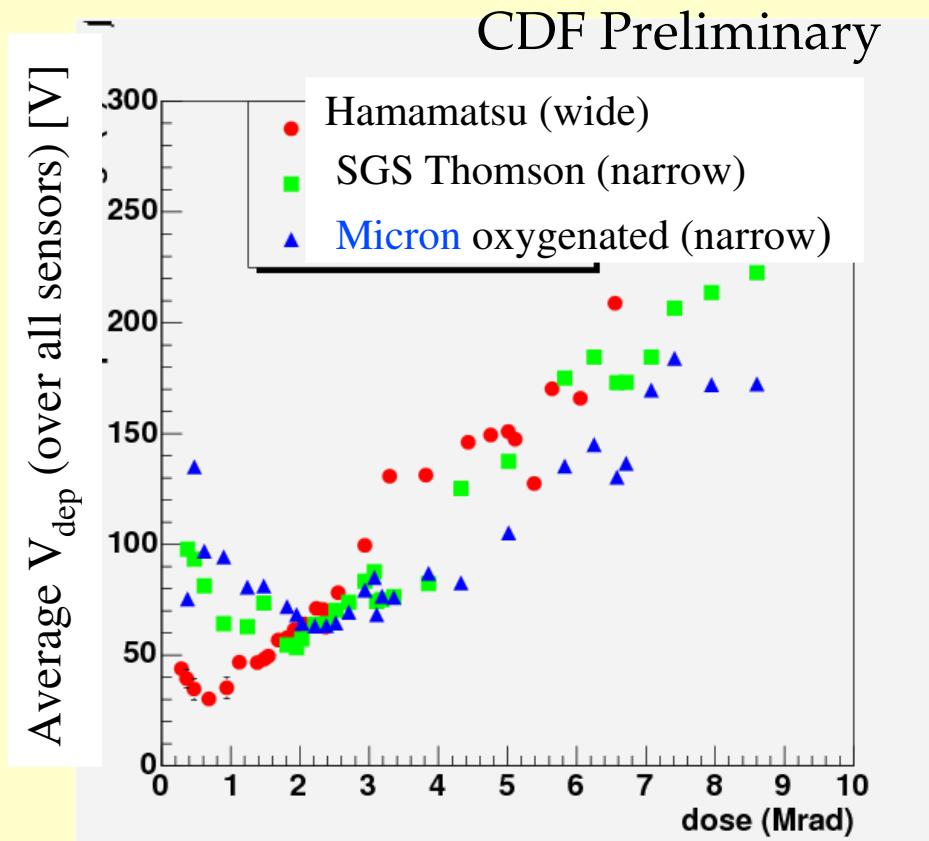


Linear fits and extrapolations for
ALL sensor modules of L00:

- Operational limit at ~ 500 V
- A few sensors are reaching the operational limit for a full V_{dep} and becoming under-depleted

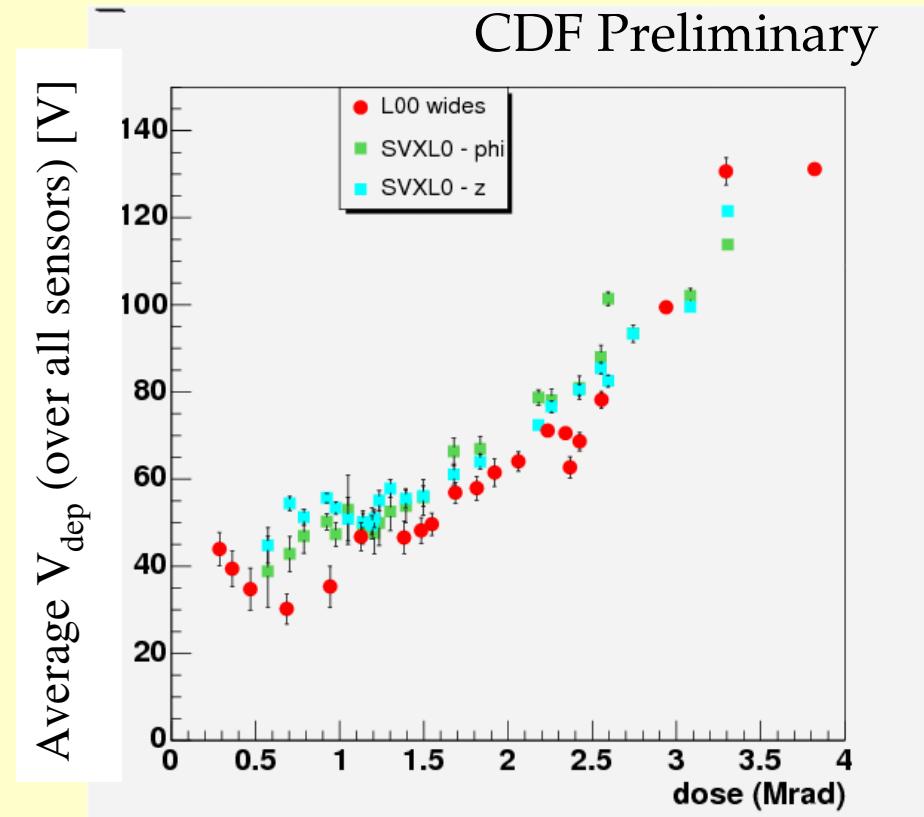
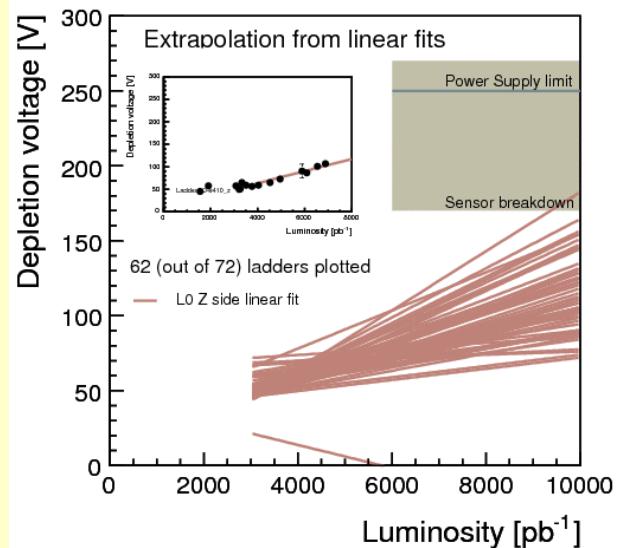
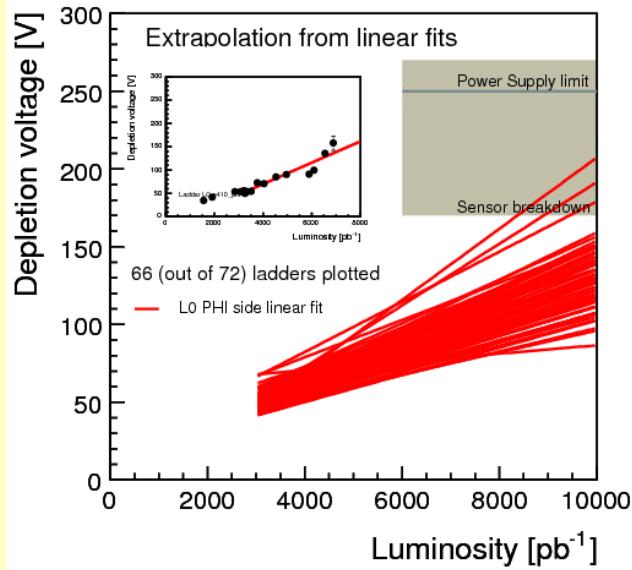
Conversion of Luminosity to Radiation Dose for L00

Using the measured radiation field and knowing the position of the silicon sensors, it is possible to convert luminosity to radiation dose



The (oxygenated) Micron sensors inverted after the others, as expected

Depletion Voltage for SVX - L0

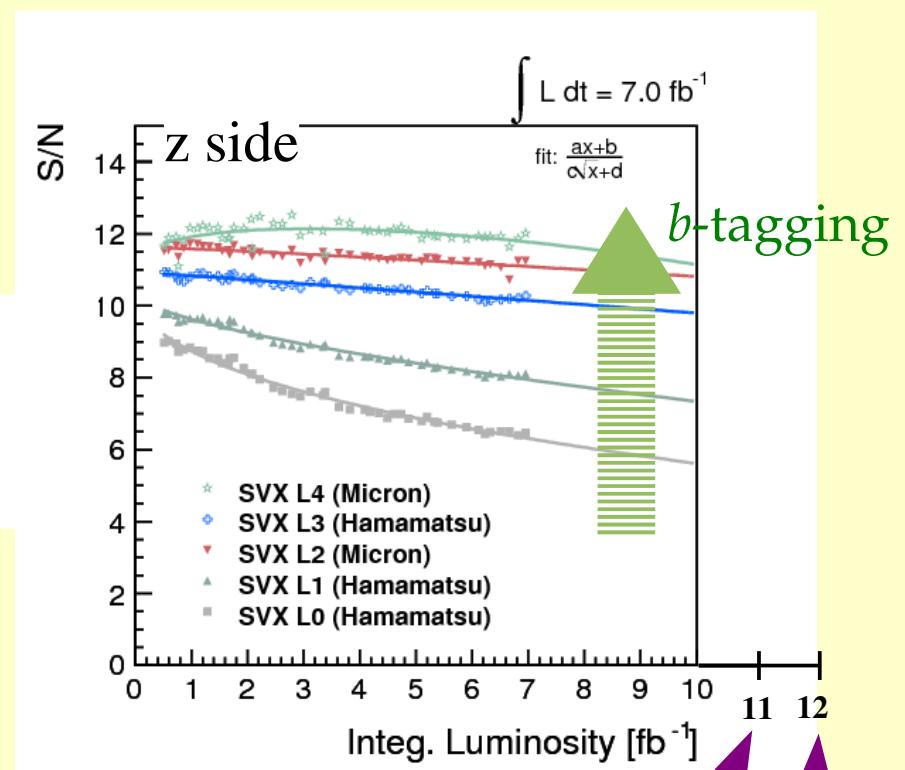
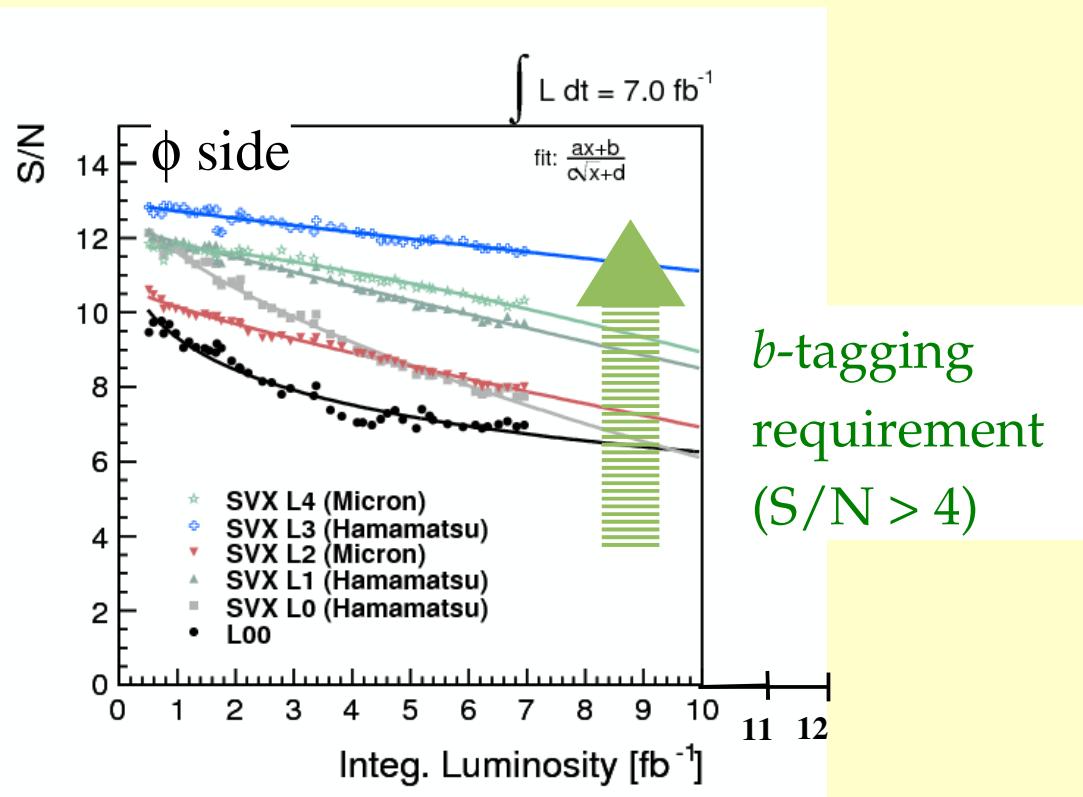


- SVX-L0 Operational limit: sensors may break down at $V_{\text{bias}} > 170 \text{ V}$
- Some ladders may become under-depleted soon

Global Performance

Signal-to-Noise ratios for L00 and SVX

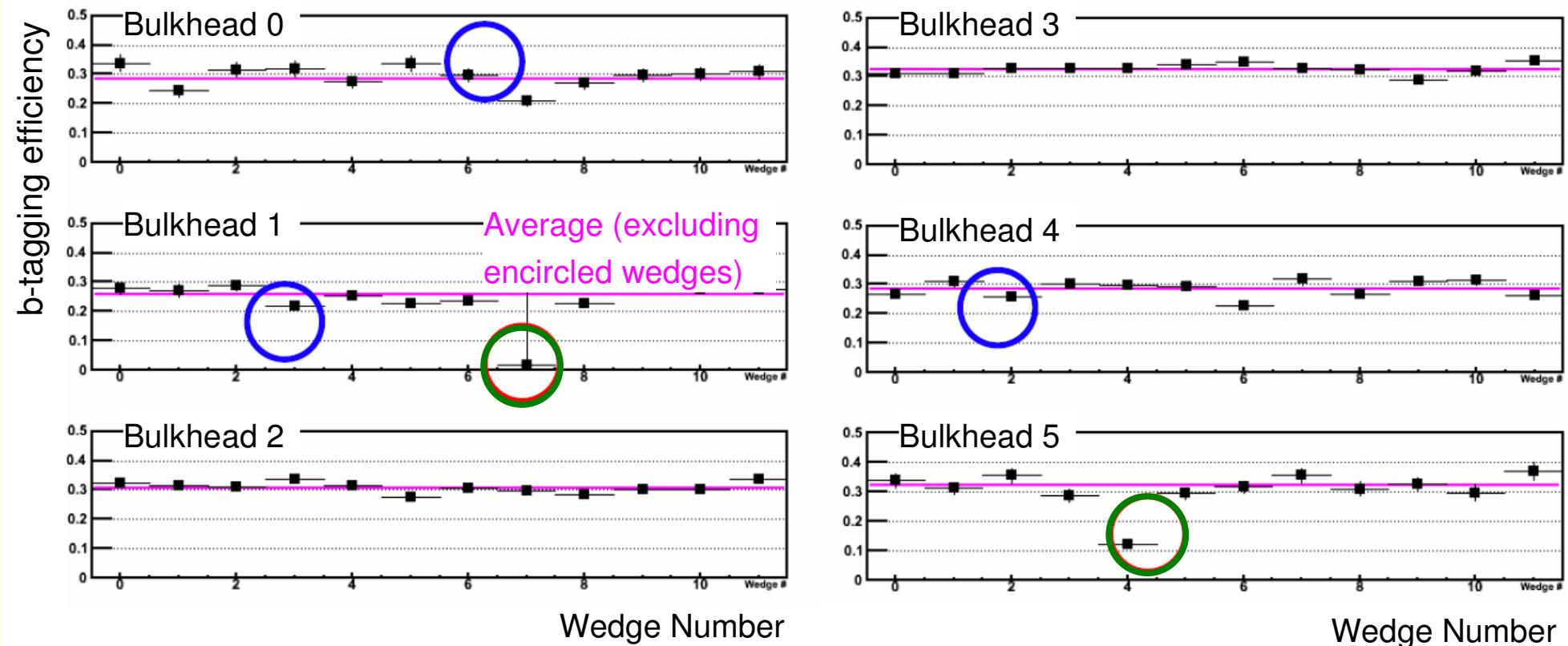
- Signal measured from data events J/Ψ to muons
- Noise estimated from calibration runs with beam



- S/N will be still good for b-tagging
- SVX-L0 degrades the fastest

Now
End of collisions

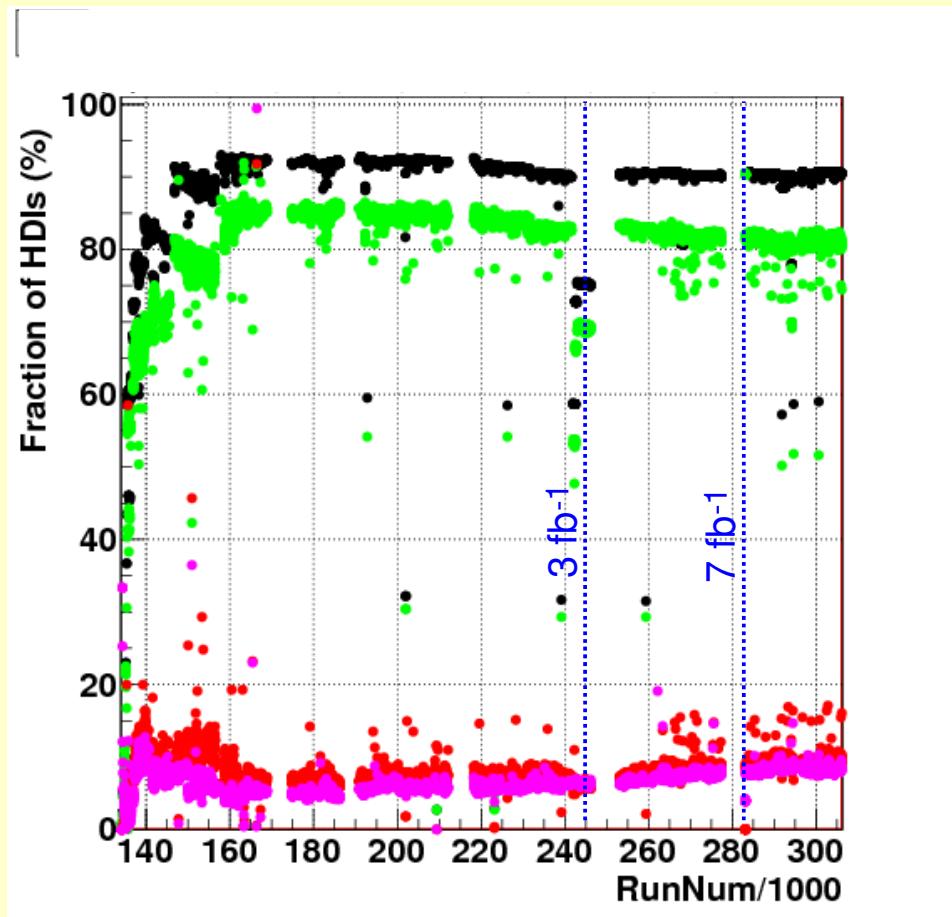
How much does a dead SVX-L0 impact b-tagging?



- Plot depicts b-tagging efficiencies estimated with data, for jets whose axis passes through SVX -L0
- Blue circles indicate wedge where sensor in layer L0 is not taking data
- Green circles indicate whole wedge (all layers) is not taking data

The dead of a layer L0 sensor would not degrade the efficiency so much!

Active Modules 2002-2011



The silicon system is getting good data from ~86% of the sensors and running ~92.5% of the detector.

Powered in black, **good in green**, **bad in red** and **error rate in pink**

Conclusions

- The CDF Silicon Detectors have outlasted their expected lifespan...
- and are still in good shape!
- Some sensors may become under-depleted soon in L00 and SVX-L0, but will continue in operation
- S/N ratio will still be good for b-tagging until the end of online operations

Tomorrow in the Poster Session:

Kyle Knoepfel,

“Aging Studies of the CDF Run II Silicon Detector”

*Aging
studies*

Tim Harrington-Taber,

“Operational Experience of the CDF Run II Silicon Detector”

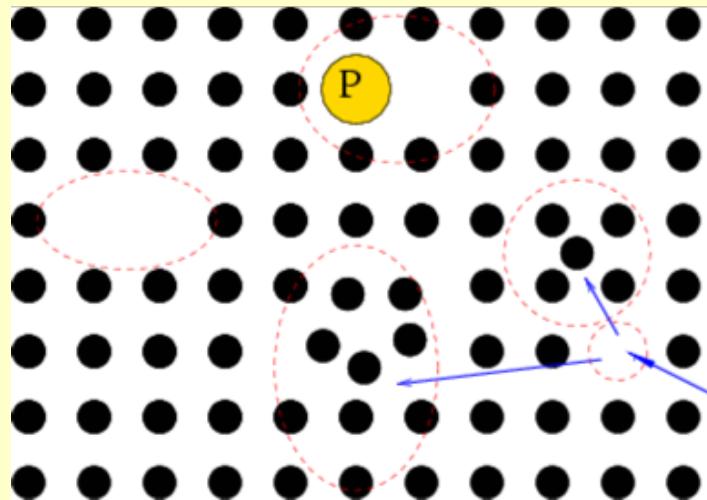
*Operational
experience*

Back-up Slides

Radiation Damage on Silicon Crystals

Radiation produces crystal defects

sensor bulk "n"



- Vacancies
- Interstitials (displaced atoms)
- Complexes: divacancies, P-vacancy,...
- $E > 12 \text{ KeV}$, clusters of defects (~ 100 lattice displacements)

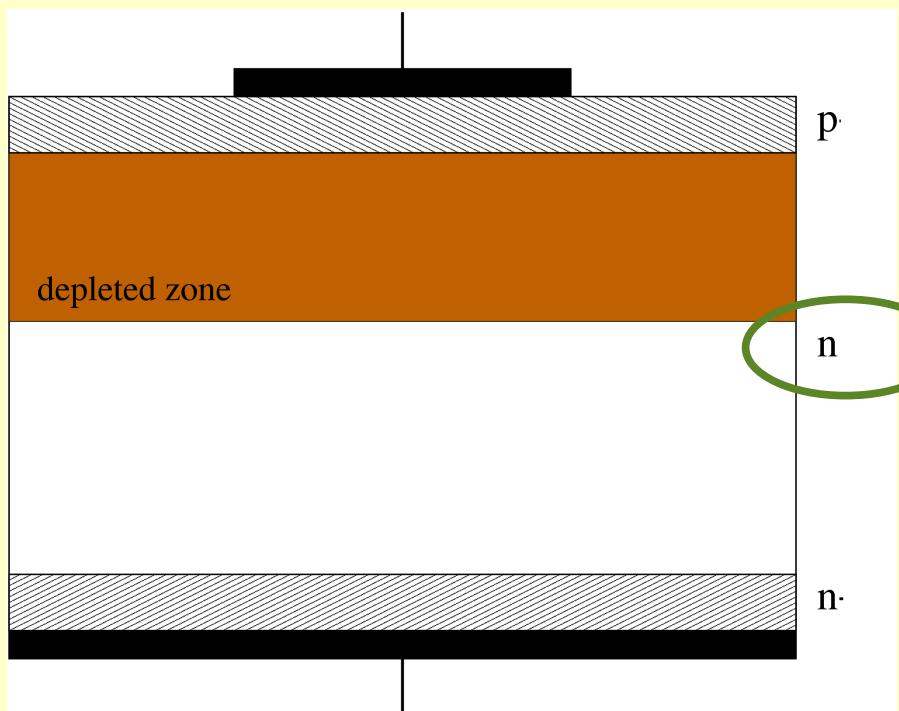
Defects change electrical properties:

- Creation of multiple energy levels between Valence and Conduction Bands
- Trapping of signal charges
- Donor removal and acceptor creation (mainly)
- Density of space charge is changed

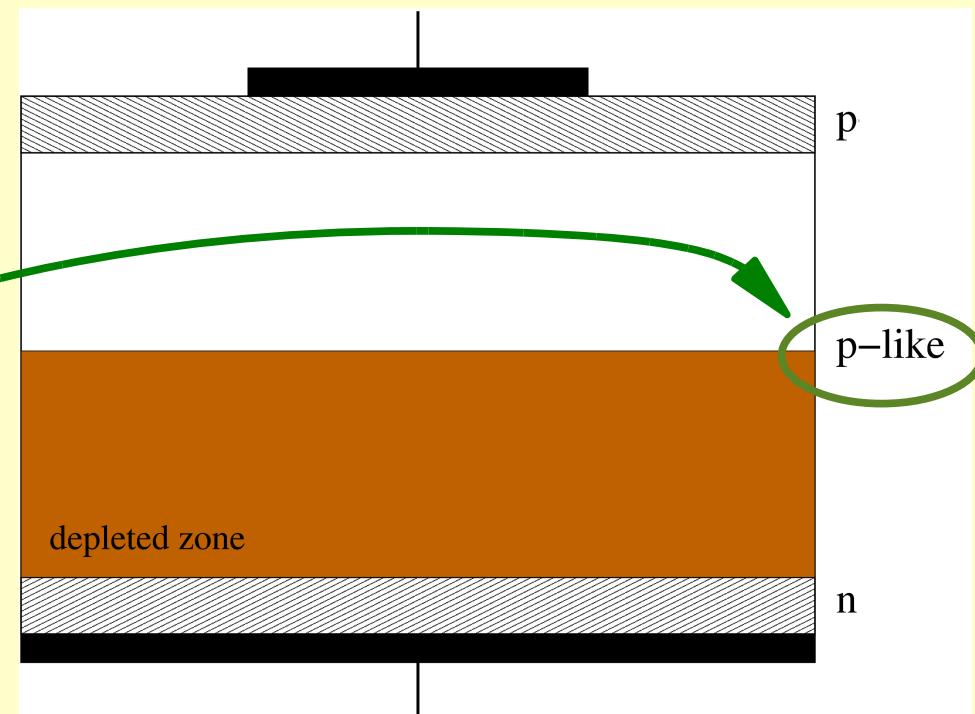
Type Inversion

An under-depleted single sided sensor looks:

Before inversion

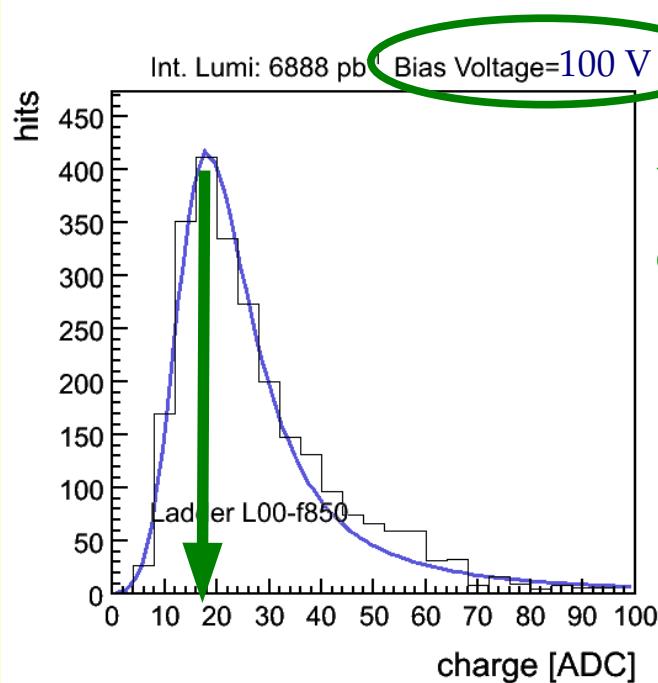


After inversion

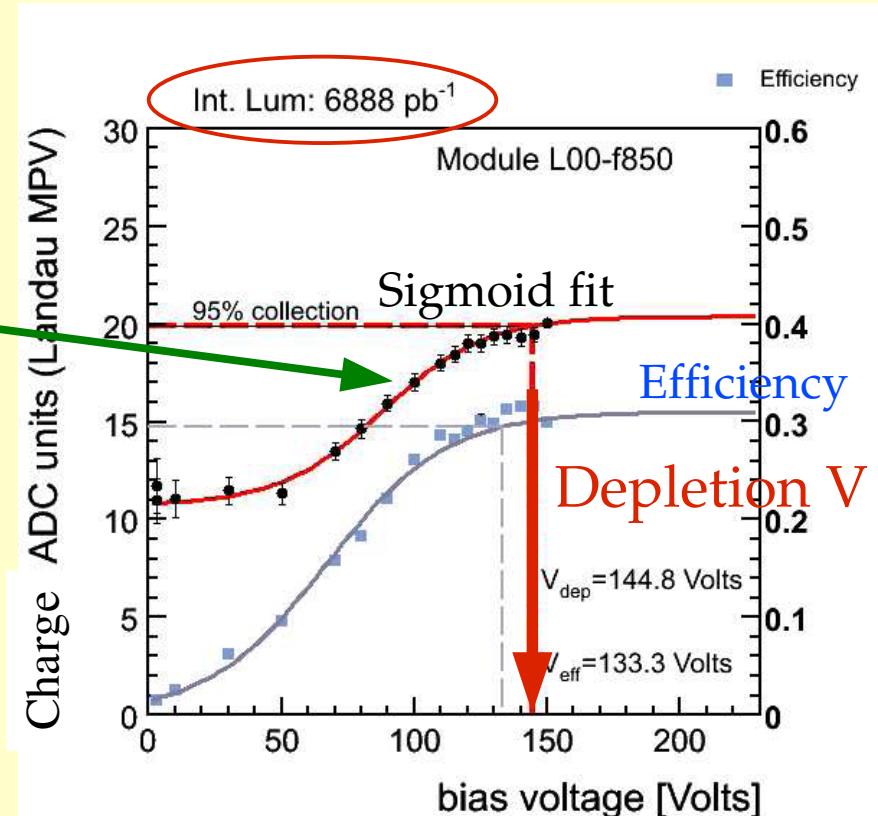


“n” bulk turns into “p-like” type

Extraction of Depletion Voltage of a Sensor



Landau fit for
each point



Collect data at several V_{bias} settings.

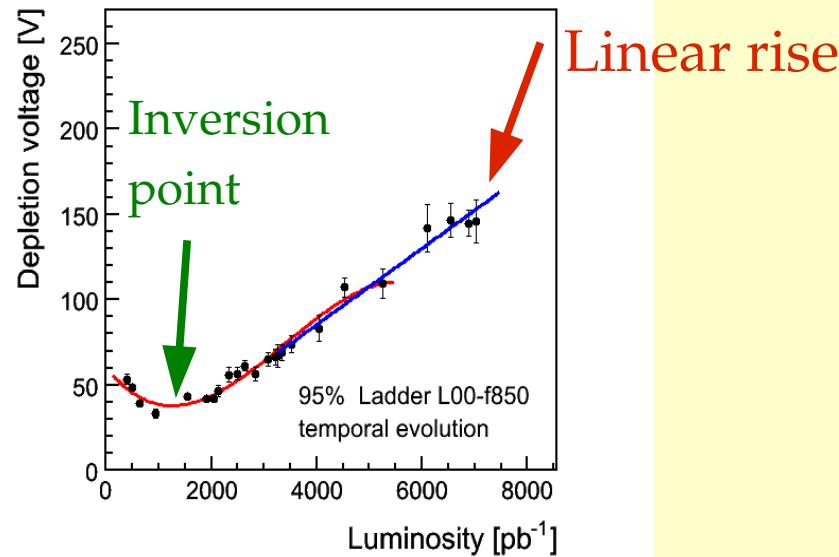
For each setting:

- Landau fit (gaussian convoluted) of charge distribution
- Extract the Most Probable Value (MPV) of the charge

- Plot Charge vs V_{bias} for each settings
- Sigmoid fit
- Define V_{dep} as 95% of plateau

Efficiency follows the trend of the V_{bias}

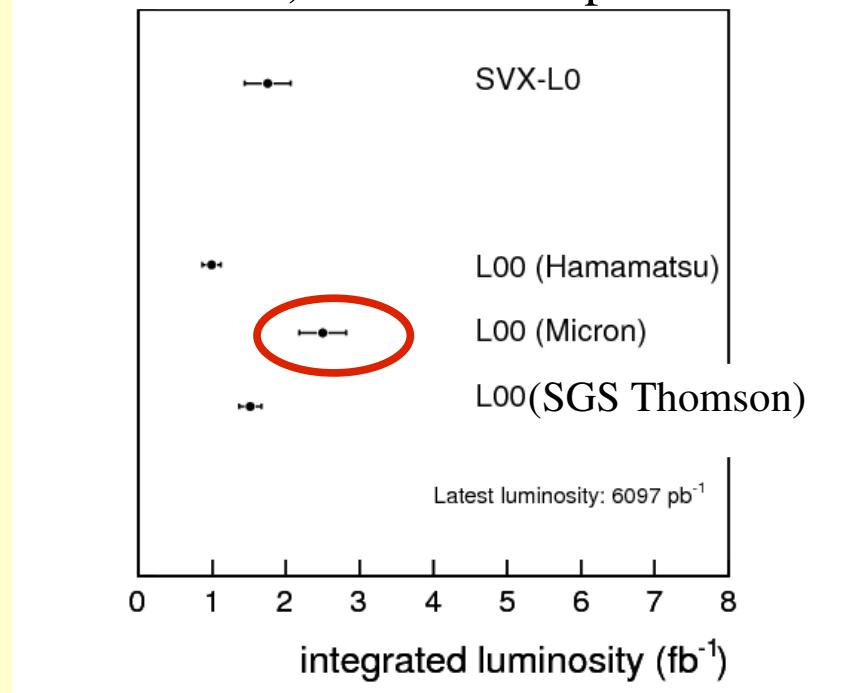
Evolution of Depletion Voltage



Extract the V_{dep} from measurements at different integrated luminosities:

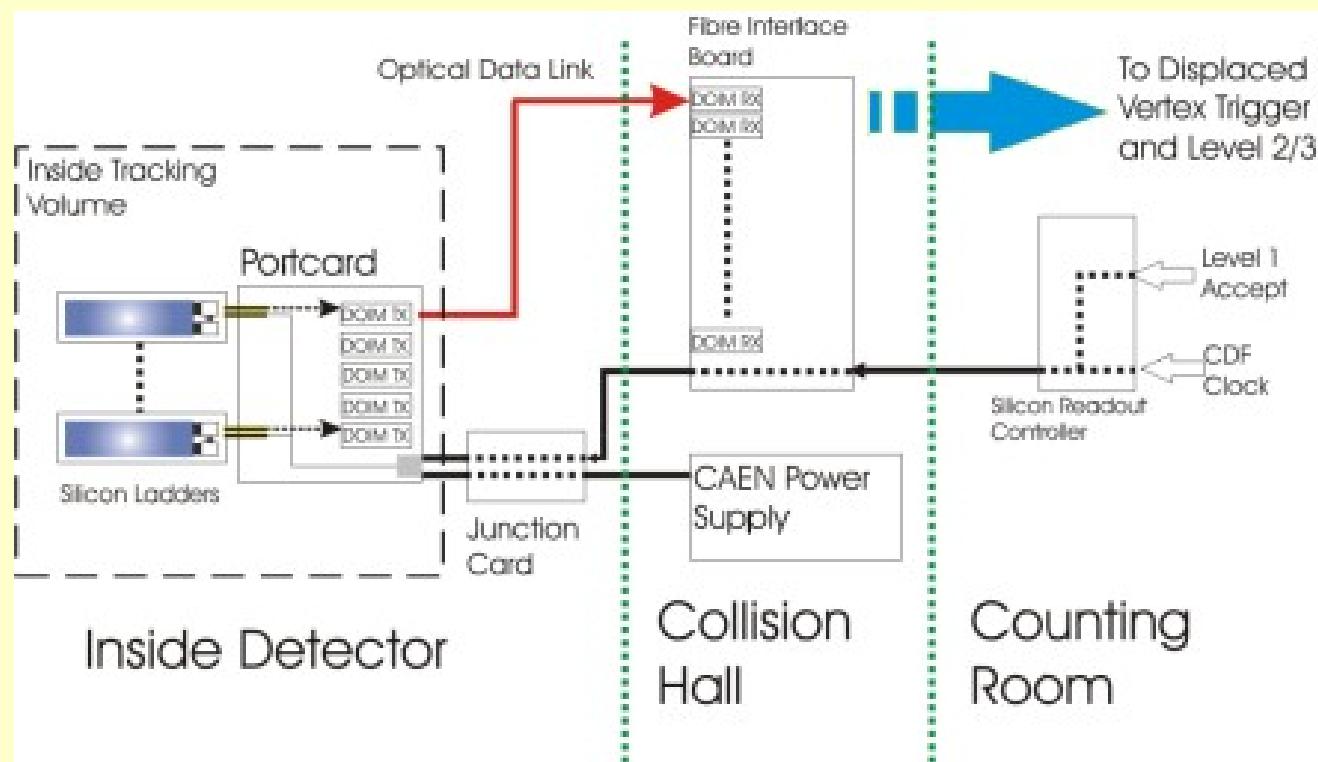
- Fit a 3rd degree polynomial around minimum
- Fit a line beyond inversion point

Average luminosity (over all sensors of each kind) at inversion point

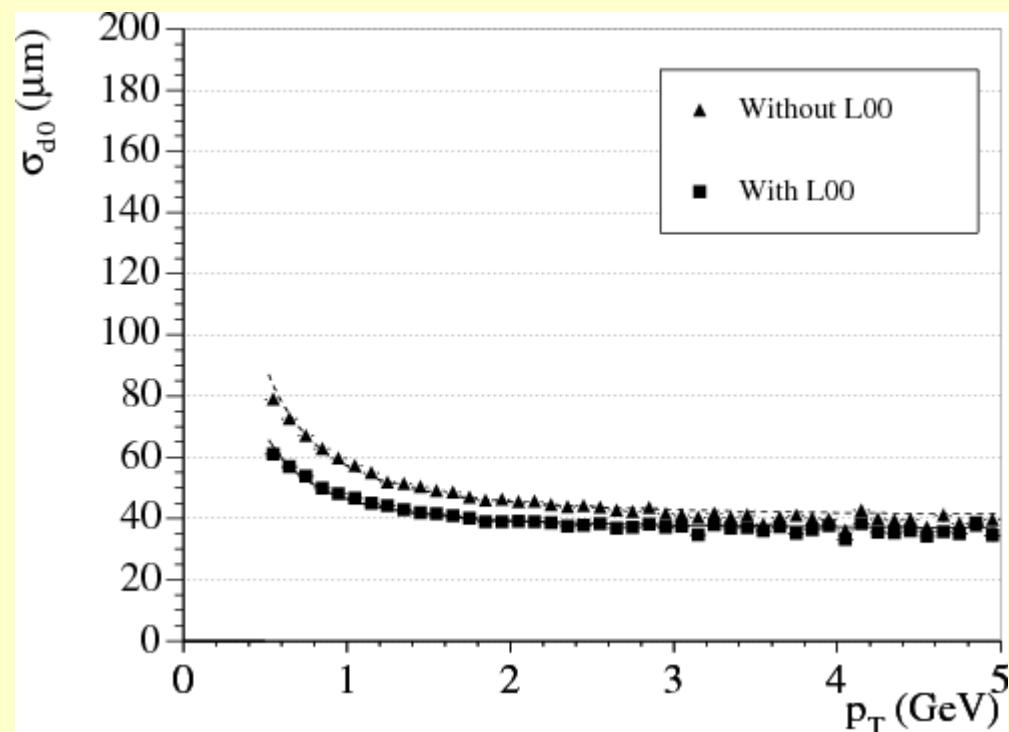


Oxygenated Micron sensors invert after the others

DAQ System



Resolution



The impact parameter d_0 is defined as the shortest distance in the r - ϕ plane between the beamline and the trajectory of the particle obtained by the tracking algorithm fit.

A Model of Radiation Damage

Effective doping concentration
of “n”-type silicon

$$\Delta N_{\text{eff}}(\Phi, t, T) = \Delta N_C(\Phi) + \Delta N_Y(\Phi, t, T)$$

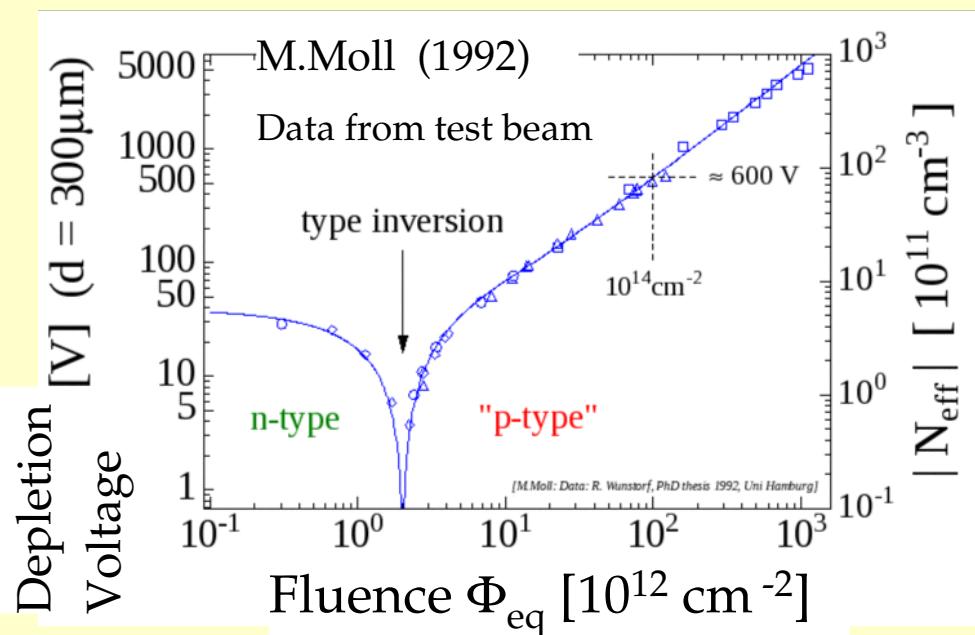
Two mechanisms: Donor
Removal
and Acceptor Creation

Increases with Φ (time
independent)

M.Moll, *PhD Thesis*, (1992) Uni Hamburg;
papers by RD2, RD50 Collaborations,...

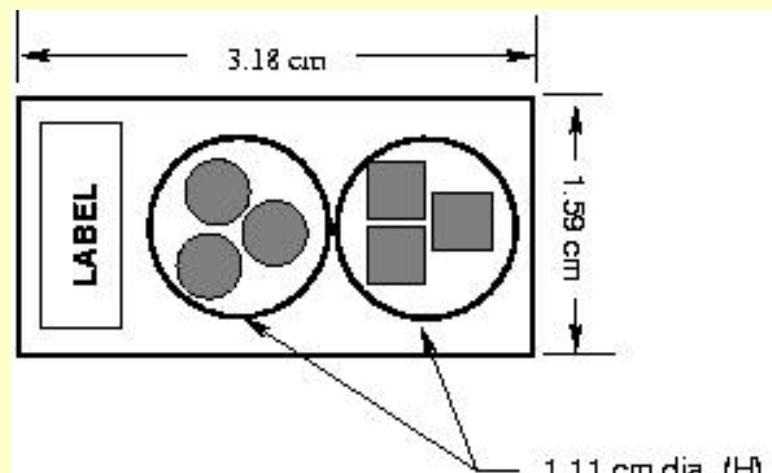
“Reverse Annealing”, (increases
with Φ , time and Temperature)

$$\Delta N_C(\Phi) = N_{C0}(1 - e^{-c\Phi}) + g_C \Phi, \quad \Delta N_Y(\Phi, t, T) = g_Y \Phi [1 - 1/(1 + t/\tau_Y(T))]$$



- $V_{\text{dep}} \sim |N_{\text{eff}}| d^2$
- Changes of depletion voltage with total fluence Φ (incident particles/area)
- There is a type inversion
- Increases after type inversion

TLD packages



Package containing six TLDs

Slide